Jour. of the KGS, Vol. 21, No. 2. March 2005, pp. 137~144

# A Study on Improvement of Shear Test Apparatus in the Direct Shear Test Under Constant Pressure

## 정압(CD)조건 직접전단시험에 있어서 시험기의 개선에 관한 연구

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## 요 지

직접전단시험은 측방변위 구속형의 일면·단순전단시험과 측방변위 비구속형의 비틀림 전단시험으로 대별된다. 현재까지도 가장 많이 사용되고 있는 직접전단시험은 시험기 및 시험방법과 결과의 해석 등에 몇 가지의 문제점이 있었으며, 특히 사질토에서는 강도가 과대하게 평가되는 등의 지적이 있었다. 또한 시험기구상의 제약으로부터 전단과정 중 진행성 파괴를 일으키는 점, 공시체내의 전단변형량과 전단응력이 일정하지 않기 때문에 전단변형량을 정의할 수 없는 점 등이 있다. 한편 단순전단시험은 직접전단시험의 장점을 그대로 가지면서, 공시체에 일정한 전단변형을 전달할 수 있기 때문에 전단에 대한 응력-변형량 관계를 얻을 수 있는 이상적인 시험법이라고 할 수 있다. 그러나 단순전단시험은 그 구조상, 시험기제작이 어려운 점 등 아직도 실용적인 시험기의 완성에는 도달하지 못하고 있는 실정이다. 본 논문에서는 간이 전단시험방법 및 시험기의 문제점을 개선한 개량형 일면전단시험기의 제작과 일본 지반공학회 토질시험법의 기준화과정에서 얻은 시험결과를 바탕으로 시험기의 개요와 시험법의 개선, 정압조건의 시험결과에 대해 서술하였다.

## Abstract

A direct shear test is classified roughly by one side simple shear test of confining horizontal displacement type and torsional shear test of non-confining one. Direct shear test that has been widely used so far has some problems with test apparatus, testing and the analysis, and in particular that its strength value is overestimated in sandy soils. Also, progressive failure of shearing process happens from shear apparatus restriction and because the shear strain and shear stress are erratic in specimen, we can not define the shear strain value. In the meantime, a simple shear test having advantage of direct shear test is an ideal test method that can get stress-strain relation on shear because it can deliver constant shearing deformation to specimen. However, simple shear test cannot be used practically, because its structure makes tester manufacturing difficult. This paper described a on outline of test apparatus, improvement of test method, and constant pressure test results based on the obtained from improved direct shear apparatus and the standardization of JGS soil testing method.

**Keywords** : Constant pressure condition, Direct shear test method, Improvement of test apparatus, Sand

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## 1. Introduction

Usually, test methods such as unconfined and triaxial compression tests and direct shear test to decide the shear strength parameters for the calculation of earth pressure, slope stability, bearing capacity. Unconfined and triaxial compression tests, called indirect shear tests, have failured soil specimen by axial compression, and stress on slip surface indirectly from Mohr-Coulomb failure envelope. In particular, triaxial compression test is used widely in research and practical fields because principal stress state of soil specimen is clear (Table 1 refered to).

However, as arranged in Figure 1, when the merits and demerits of direct or indirect shear test are mutually in contradictory relation perfectly, the former does constant volume test instead of undrained test, and principal stress state of specimen is indistinct, but it can measure stress on shear surface directly. Also, one side direct shear test has merits that soil specimen is smaller than triaxial test and testing is easy, and test time has short.

In addition, because it can measure a shear strength in one-dimensional consolidation, plane strain directly, in the side view of current stability calculating method using strength of slip surface, direct shear test is preferably considered in principles and practical uses.

Direct shear test is classified roughly by a one side simple shear test of confining horizontal displacement type and torsional shear test of non-confining one. Direct shear test that has been widely used so far has some problems with test apparatus and testing, and in particular its strength value is overestimated in sandy soils.

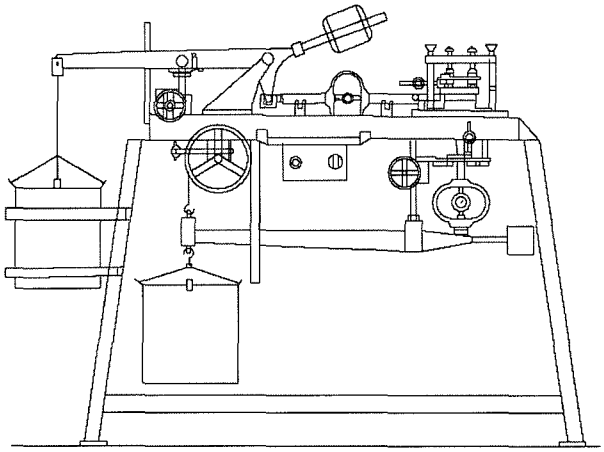


Fig. 1. Mikasa type of improved one side direct shear test

Also, progressive failure of shearing process happens from shear apparatus restriction and because the shear strain and shear stress are erratic in specimen, we can not define the shear strain value (Japanese Geotechnical Society, 2000).

In the meantime, simple shear test having advantage of direct shear test is an ideal test method that can get stress-strain relation on shear because it can deliver constant shearing deformation to specimen. But, simple shear test cannot be used practically, because its structure makes tester manufacturing difficult.

## 2. Structures of Improved One Side Direct Shear Test

This paper, on the basic of structure of the improved

Table 1. Comparisons between Direct shear and Indirect shear test

| | Direct shear | Indirect shear |
|---|---|---|
| | one side shear, simple shear | Confined Comp., Triaxial Comp. Test |
| Consolidation Condition | 1-dimension | triaxial: 3-dimension |
| principal stress condition at shear | unidentified | identified<br>(considering specimen as a element) |
| stress on shear face | identified | unidentified<br>(shear face unidentified) |
| Strain condition | enforced (plane strain) | chosed (axis directional) |
| finding shear strength | direct | indirect |
| other problems | one side : progressive failure possible | difficulty in measuring volume change of unsaturated soil |

one side shear test (Mikasa, 1960) that Mikasa (1960) proposed as seen in Figure 1, describes manufacturing test apparatus, testing, results arrangement that is applied to one side shear test method (JGS 0561 - 2000) under constant pressure (CD) condition, which improved problems of existing one side shear test apparatus.

Consequently, this paper introduces a method to improve existing problems at shear test, overview of the newly improved one side direct shear test apparatus, and shearing test result under constant pressure (CD) condition as an example.

## 2.1 Current One Side Shear Test (Simplified Shear Test)

Currently widely used test methods by shear test apparatus (Figure 2 refered to) that is prescribed to Korean Industrial Standards KS F2343 「direct shear test of soil - consolidated drained condition」 are as follows,

① pedestal is not fixed to pressure shaft, and inclined while shearing.

② while shearing, control (constant volume control) of normal stress is impossible.

③ There is a problem that is not suitable in test standard, which because normal load gauge is established in pedestal side, can not confirm stress that is applied to reaction plate.

Therefore, undrained-conditioned tests using this test apparatus do with the fast rate to normals to constant volume shear test results because it is impossible to control vertical volume change (in case of clay specimen, 1～2 mm/min, rapid shear, CU condition).

Also, drained-conditioned tests do with the slow rate not to generate excess pore water pressure (in case of sand specimen 0.2 mm/min, in case of clay specimen, 0.02 mm/min, slow shear, CD condition).

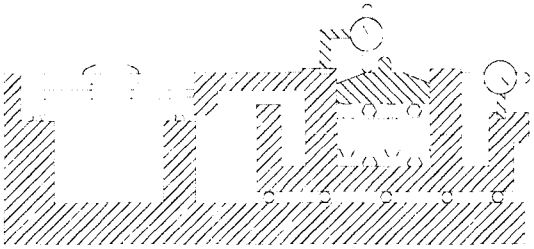


Fig. 2. General shear test

In case of rapid shear, vertical displacement contracts and expands, which shear strength is overestimated and underestimated. In case of slow shear, vertical displacement contracts and expands, which shear strength is intended to be overestimated and underestimated because of effects of side friction force (Japanese Geotechnical Society, 1997), (Japanese Geotechnical Society, 2000).

## 2.2 Improvements and Problems of Existing Shear Test (Japanese Geotechnical Society, 2000)

Mentioned in detail one side shear test has more various advantages than triaxial test, is preferably considered in practical use, but because it puts specimen in hard shear box that is detached up and down, establishes separation space of top and bottom shear box, (move any one side of high low class shear boxs) moving relatively. It had some problems like strong confinement, progressive failure from shear box end, effects of side friction, effects of grain diameter in sandy soil also. However, these problems are solved and test results become more reliable and applicable.

### (1) Relation Between Specimen Size and Allowed Grain Diameter Using Sand in Constant Pressure Test

A confinement for deformation is strong in one side shear test, and when it uses specimen that exceeds allowed grain diameter, strength is exaggerated.

In coarse grained soils on this account, minimum size of specimen for maximum grain diameter and allowable maximum grain diameter of specimen for the size of specimen need to be made clear.

Here, in sand specimen without fine-grain, specimen diameter 70 times of maximum diameter of specimen is available. In well-graded specimen with fine-grain, this condition is mitigated and 30 times of maximum diameter of specimen is considered suitable.

### (2) Effects of Side Friction in One Side Shear Test

Side friction is volume change of soil accompanied with shear, that is, occurs between specimen and shear box inside by dilatancy. Because of this increase or decrease of normal stress of shear face, strength gets exaggerated or is made small. It displays normal force change on shear face by side friction direction and in shear box in shear test under the constant pressure condition in Figure 3.

Figure 3 (1) shows that specimen expands by dilatancy of positive (+). Upward side friction force happens and increases normal force on shear face in fixed box inside. Figure 3 (2) show that specimen contracts by dilatancy of negative (-). Downward side friction force on the contrary to Figure 3 (1) happens and reduces normal force on shear face. Constant pressure shear strength in Figure 3 (1), (2) respectively is exaggerated and very small because of the change of normal force.

Load gauge was established to reaction plate and measured directly for the change of such normal force to consider effects about side friction. Consequently, $\phi_d$ is obtained by normal stress on pedestal, which looked tendency to exaggerated and very small respectively by 5° dilatancy of positive (+), negative (-).

### (3) Separation Space of Top and Bottom Shear Box and Deformation Specimen Inside in One Side Shear Test

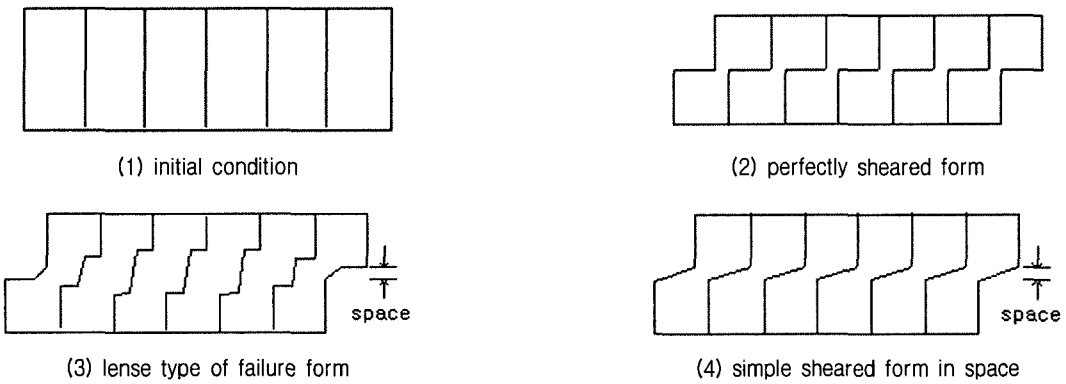
Deformation state of ideal specimen in one side shear test is sheared by single face in Figure 4 (2). Actuality one side shear test causes uneven deformation that adopts type of progressive failure so that breakdown is gone from the end because deformation is converged on before and behind the end of shear box like Figure 4 (3).

Effects that this causes to shear strength, have two-faced that is strength decline by progressive failure and strength increase by face of specimen end.

In the meantime, ideal deformation in direct shear test is considered as form of simple shear. This does make separation space of top and bottom shear box more than the width (10~20 times of average grain diameter $D_{50}$) of shear layer, then, deformation form of simple shear is shown in the separation space of Figure 4 (4) that is not the form of progressive failure.


(1) Positive(+) Dilatancy (2) Negative(-) Dilatancy

Fig. 3. Effects of side friction force under constant pressure condition




(1) initial condition (2) perfectly sheared form

(3) lense type of failure form (4) simple sheared form in space

Fig. 4. Space between shear boxes and deformation of specimen inside

Consequently, in constant pressure shear test that uses specimen of comparatively big spherical cross section, it is reported that strength is exaggerated because it can disturb free development of shear layer which the size of separation space is small.

And in constant pressure shear test using sand dilatancy behavior tends to appear greater than one side shear test.

An example of friction angle show that in loose condition a single shear is larger, and in dense condition a simple shear is tended to appear larger.

## 2.3 Structure of Improved One Side Shear Tester

A single shear test apparatus shown as Figure 5 that solves problem of existing direct shear test as discussed in 2.1. Improved shear test apparatus with a single shear surface that established load gauges among pedestal side, upper pressure plate and reaction plate, has the structure that can measure loading pressure and pressure of reaction plate directly.

Normal stress transfers air pressure and loads through cylinder, loading pressure of maximum 7.5 kgf/cm$^2$ may be available.

Shear force is a form that controls the deformation amount by motor of screw jack type. Constant volume test by this type acts high-handily, tests regulating displacement of pressure shaft lest the vertical transformation amount should happen. Constant pressure shear test is controled so that normal stress measured in reaction plate may be kept always changeless.

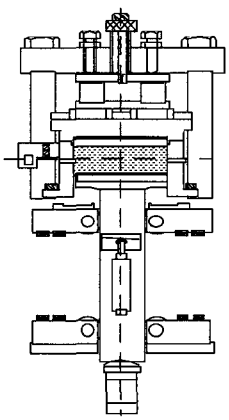
Consequently, this test apparatus is manufactured so that test of various size is available exchanging shear box of diameter and height of specimen, 60 mm × 20 mm, 90 mm × 30 mm, 120 mm × 40 mm, 150 mm × 50 mm (Ohshima A., Morimoto K., 2002).

## 2.4 Comparisons of Test Results Between Current Direct Shear Test and Improved Direct Shear Test Under Constant Pressure Condition

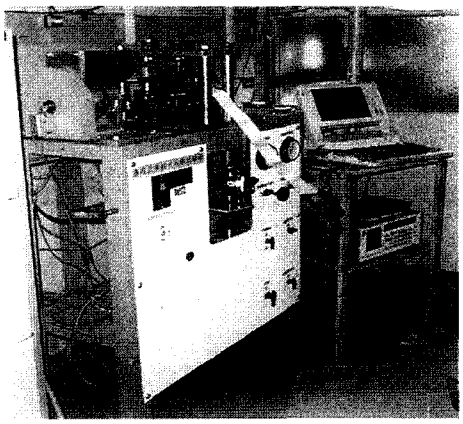
Using current direct shear apparatus and improved model box shear apparatus with a single shear surface in 2.1, shear test with constant pressure (CD) condition is performed and the results shown as Figure 5 (Takada N., Ohshima A., Sakamoto K., 1996). To compare test results, tests are done on equal condition for test specimen and size.

If results in Figure 6 are examined in detail, as indicated before, simplified shearing test results are exaggerated as improved one side shear test results when dilatancy of shear process contracts because relative density is low. Simplified shear test results are very small as improved one side shear test results when dilatancy of shear process expands because relative density is high.

And in the case of existing simplified shear test, vertical pressure that is measured from upper in shear process of CD condition, continues to changed regardless of relative density Dr.



(1) structure of shear box



(2) shear tester

Fig. 5. Constant volume-constant pressure type of one side shear tester

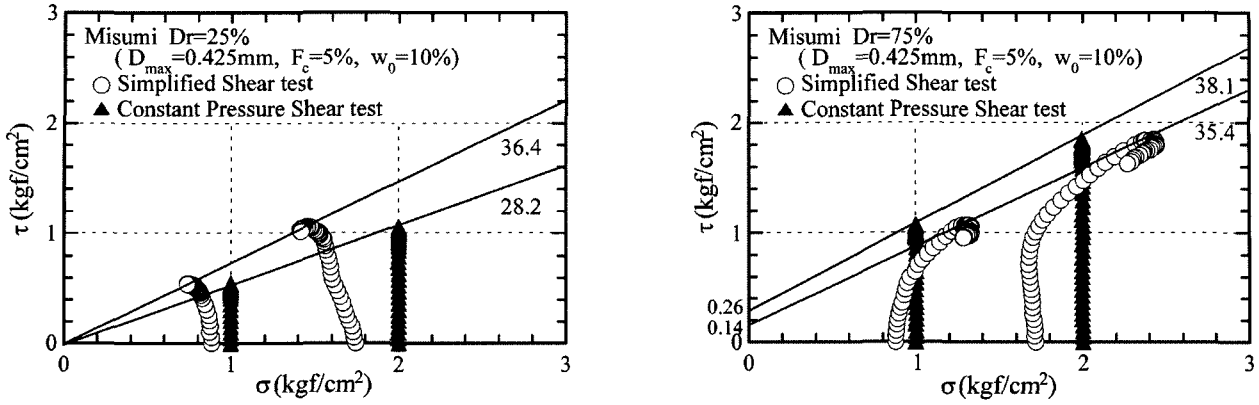



Fig. 6. Comparisons of direct shear test and improved shear test in CD condition

Therefore, we can know definitely that it is not satisfied with CD condition, and as a result, error is shown in measured strength parameters.

## 3. Constant Pressure (CD) Shear Test Using Improved Direct Shear Test

### 3.1 Testing Materials and Method

Physical properties of the sand used in the test shown as Table 2, and grain size distribution shown in Figure 7. Testing method is that space of top and bottom shear box by 0.2 mm was separated after being consolidated by established pressure first.

Through monitoring with shear test starting after the shear speed 0.2 mm/min, constant volume one side shear test regulates displacement of pressure shaft lest the vertical deformation should happen. Constant pressure shear test controls loading pressure so that normal stress of fixed load between upper part pressure plate and reaction plate may be fixed. When shear displacement exceeds 7 mm of diameter, test is ended.

### 3.2 Results of Constant Pressure (CD) One Side Shear Test

Results of constant pressure one side shear test shown as Figures 8, 9.

From relation of shear stress and deformation value of Figures 8 (1), 9 (1), in loose case of Dr = 25%, definite maximum shear strength is not appeared, but steadily and increasingly changes. In dense case of Dr = 75%, definite maximum shear strength is appeared.

Dilatancy of shear process is exposing contraction by loose case, and swelling appears in dense case.

In Figures 8 (2), 9 (2), $\sigma_U$ and, $\sigma_L$ are measuring value of loading gauge that is established to each upper part, lower part of pedestal. It is known that loading pressure of pedestal and observed value of reaction plate are different.

By considering effects of side friction with shear box

Table 2. Physical properties of sands

| | |
|---|---|
| $D_{max}$ (mm) | 0.425 |
| $D_{50}$ (mm) | 0.174 |
| $F_c$ (%) | 5.8 |
| $U_c$ (g/cm$^3$) | 1.3 |
| $\rho_s$ (g/cm$^3$) | 2.67 |
| $\rho_{dmax}$ (g/cm$^3$) | 1.516 |
| $\rho_{dmin}$ (g/cm$^3$) | 1.279 |
| $w_{opt}$ (%) | 19 |

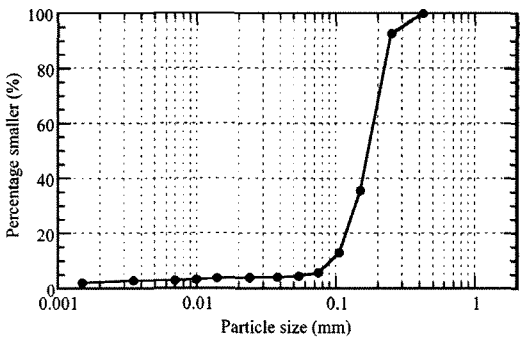
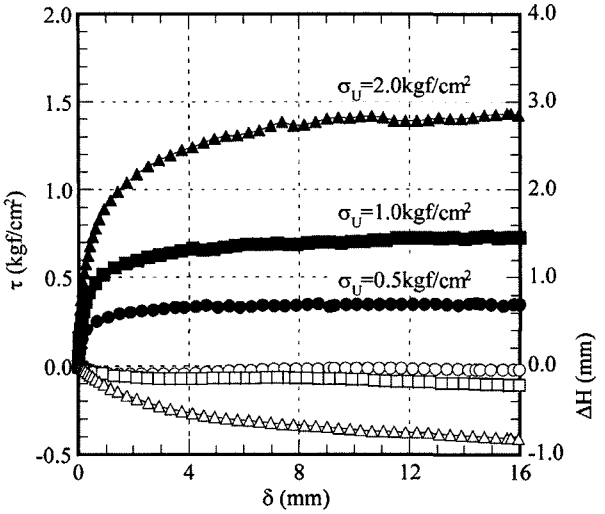
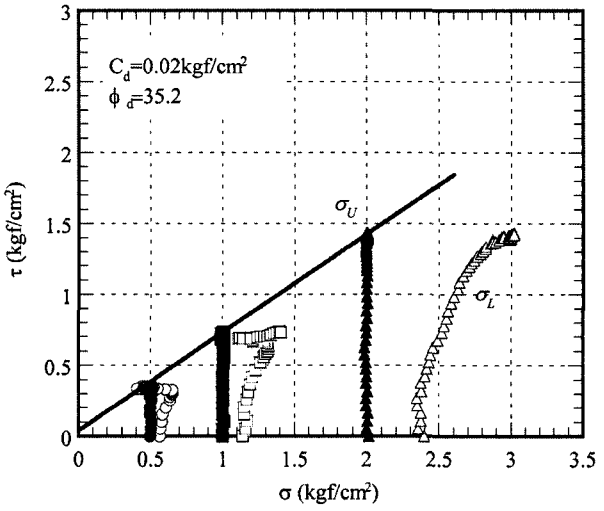



Fig. 7. Grain size distribution of sands

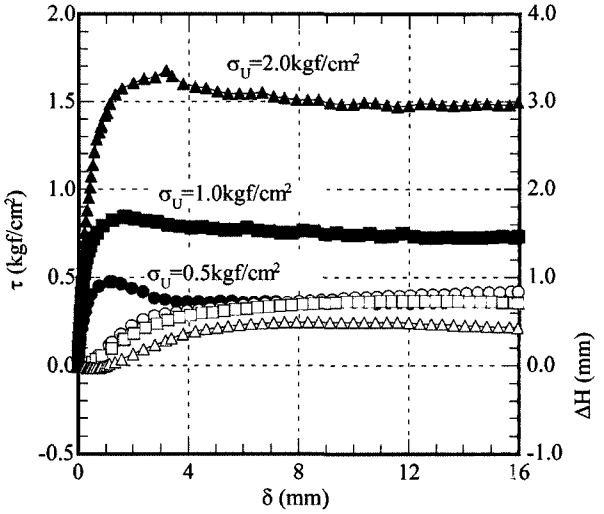



(1) Relationship (τ)-(δ)

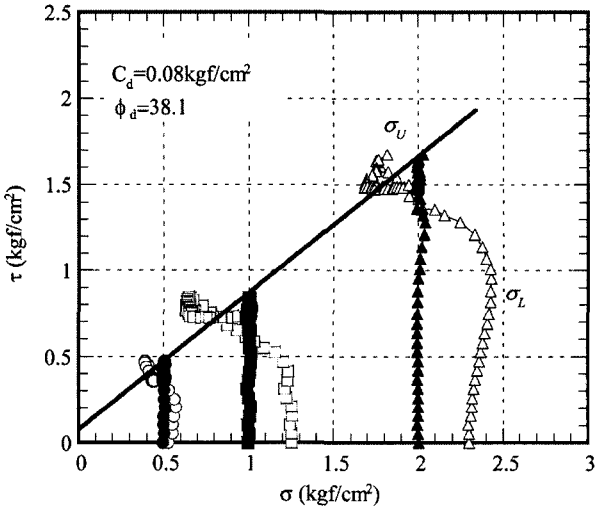



(2) Relationship (τ)-(σ)

Fig. 8. Results of shear test at CD condition (at Dr=25%)




(1) Relationship (τ)-(δ)




(2) Relationship (τ)-(σ)

Fig. 9. Results of shear test at CD condition (at Dr=75%)

and specimen skin side controlling by value of reaction plate.

It is known that this is one side shear test that reappears well truly meaning constant pressure shear condition. Consequently, $\phi_d$ is obtained by normal stress on pedestal, which is exaggerated and is very small respectively by 5° dilatancy of positive (+), negative (-) (Kim, Jae-young et al, 2004).

## 4. Conclusions

Comparatively, in the one side direct shear test, test apparatus and test method are very simple and satisfied with the condition such as one-dimensional consolidation, plane strain in real field.

Currently widely used test methods (so-called simplified shear test) by shear test apparatus that is prescribed to Korean Industrial Standards KS F2343 「direct shear test of soil - consolidated drained condition」 are not satisfied with drained condition perfectly, and this test is not in various usages.

This paper, describes an outline of test apparatus, improvement of test method, and constant pressure test results based on the test results obtained from manufacturing the improved direct shear apparatus with a single shear surface and standardization of JGS soil testing method

that solves problems of simplified shear test method. Test results are :

(1) Improved model one side shear test apparatus was made better to control measuring normal stress directly on sheared face through loading gauge established in reaction plate, and drain condition and stress state of shear process are satisfied with test condition. So, it is known that this test method may get corrected strength parameters.

(2) Proposed constant volume one side shear test regulates displacement of pressure shaft lest the vertical deformation should happen. Constant pressure shear test controls loading pressure so that normal stress of fixed load between upper part pressure plate and reaction plate may be fixed, and shear displacement is measured.

(3) From relation of shear stress and deformation value, in loose case of Dr = 25%, definite maximum shear strength is not displayed, but steadily and increasingly changes. In dense case of Dr = 75%, definite maximum shear strength is displayed.

Dilatancy of shearing process is exposing contraction by loose case, and expansion appears in dense case.

(4) Constant pressure shear test that makes use of improved shear test apparatus with a single shear surface is considered as a standard that keeps normal stress (reaction plate) constant. However, when simplified constant pressure shear test (normal stress on pedestal is constant) that does not control measuring normal stress in reaction plate is used, constant pressure shear strength is needed to define by vertical stress at failure.

(5) Because improved shear test apparatus with a single shear surface is easy to manufacture and control, it may confirm the reliability by reiterated tests. Studies using this testing method and test apparatus structure are few and further studies on more developed standardization of this testing method may be needed.

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(received on Mar. 9, 2005, accepted on Mar. 26, 2005)